

Diffractive heavy pseudoscalar-meson productions by weak neutral currents

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Work in collaboration with

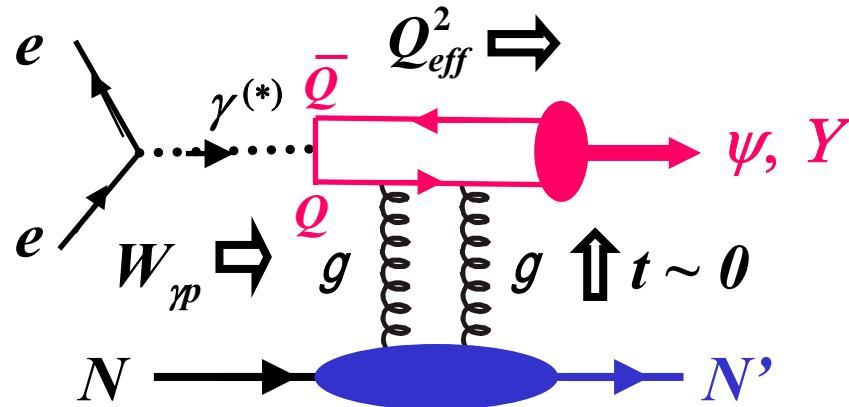
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OUTLINE

1. Motivation
2. Formulation in Perturbative QCD
3. Numerical analysis for η_c , η_b productions
(compared with J/ψ production)
4. Summary

** Diffractive process at HERA **

Elastic ψ, Y productions



Direct probe
of gluon distribution

Perturbative QCD analysis (Llog Q^2 approx., eikonal approx., NR approx.)

$$\left. \frac{d\sigma_{el}^{\gamma p \rightarrow \psi p}}{d|t|} \right|_{|t| \sim 0} \propto \frac{\alpha_s^2(Q_{eff}^2)}{Q_{eff}^6} [xG(x, Q_{eff}^2)]^2$$

HERA ($x = Q_{eff}^2 / W_{\gamma p}^2 \geq 10^{-5}$) + other DIS experiments

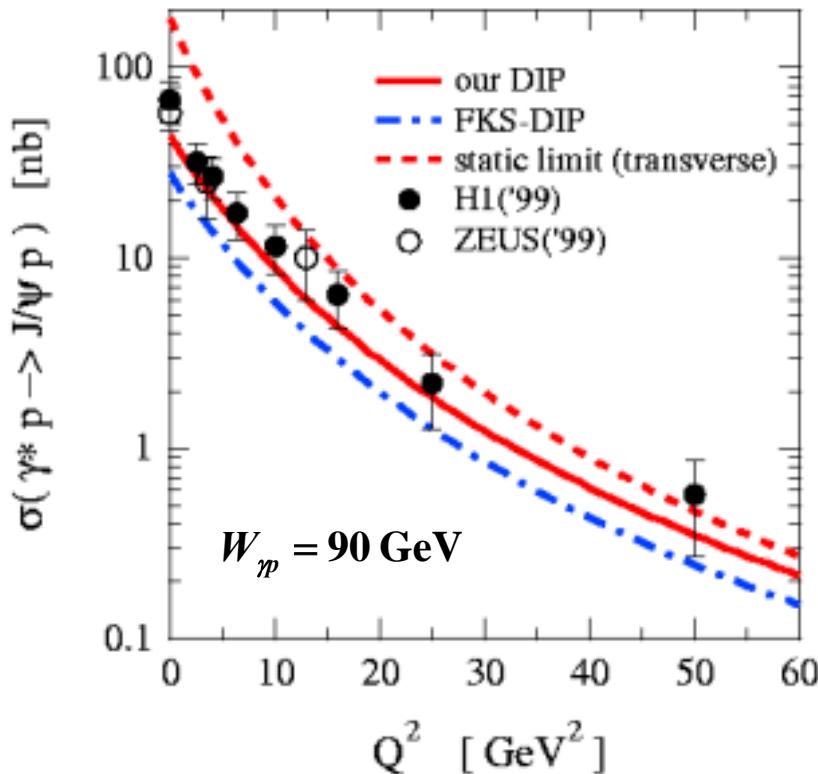
Detailed determination of parametrizations over wide x -region

** total cross section (HERA) v.s. PQCD **

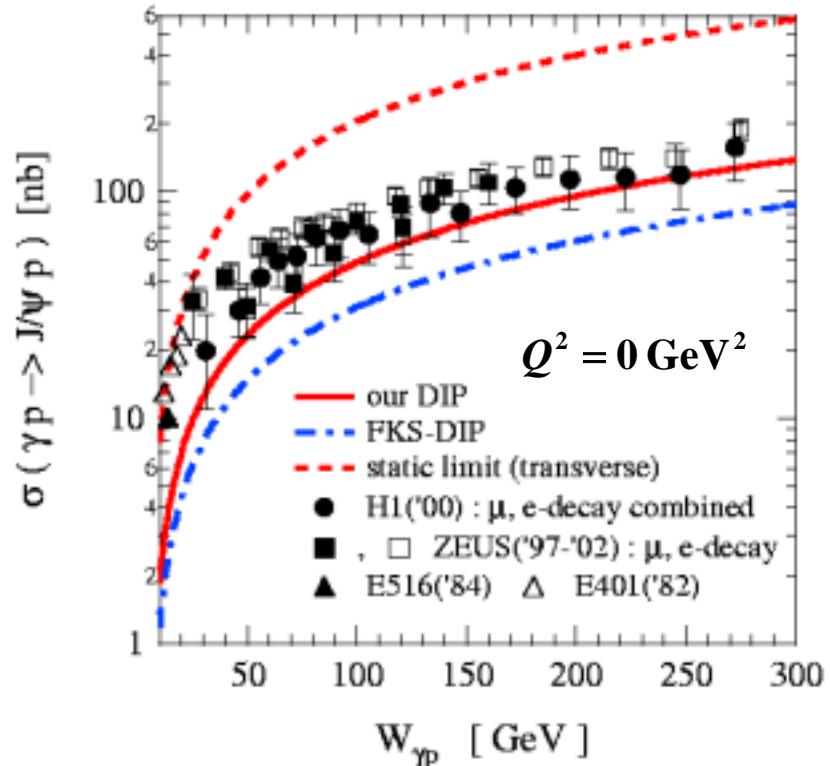
GRV95NLO parameterization

Leading log Q^2 approx., Relativistic corrections to $c\bar{c}$ pair

** Q^2 dependence (J/ψ) **



** W dependence (J/ψ) **



→ Successful PQCD analysis for J/ψ diffractive electroproduction

Can we apply the same technique to other meson productions?

** Diffractive pseudoscalar-meson productions (η_c , η_b) **

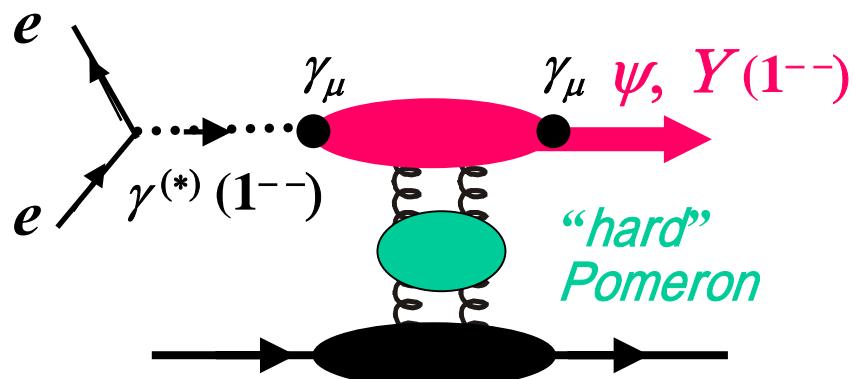


Motivation

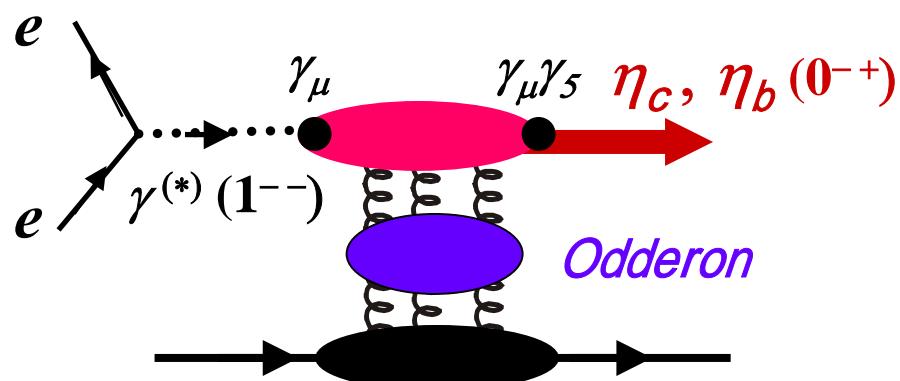
- * Direct η_c , η_b productions \leftrightarrow *M1 transitions from J/ψ , Y productions or B meson decay in e^+e^- or $p\bar{p}$ reactions*
- * Clarify level scheme of η_b (not observed)

A possible signal from 2γ decay (ref. $\Gamma_{\eta_c \rightarrow 2\gamma} \sim 10^{-4}$ MeV)

ep collision



Pomeron ($P=+1$, $C=+1$, $/l=0$)

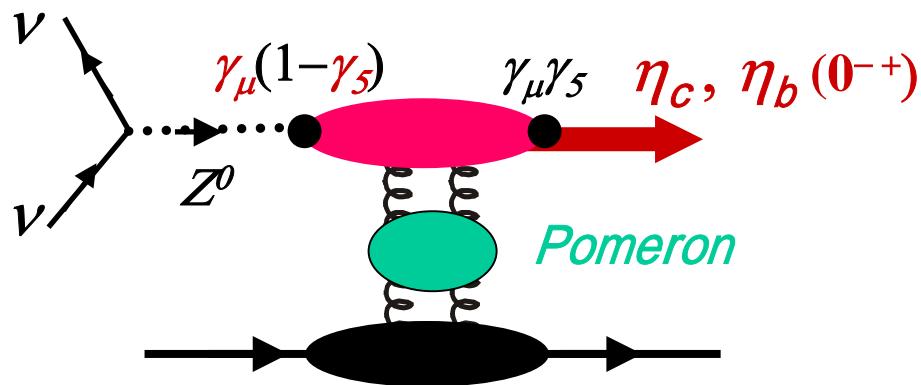
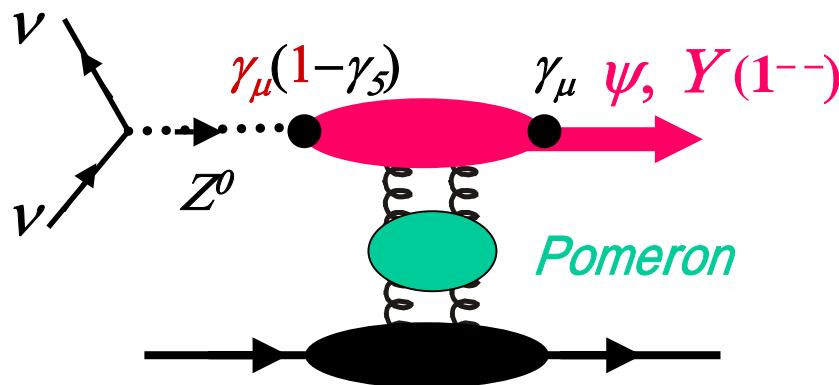


Odderon ($P=-1$, $C=-1$, $/l=0$)

- * “have not been observed”
- * “no direct relation to xG ”
- * “higher order about α_s ”

** New challenge to neutrino-induced diffraction **

νp collision

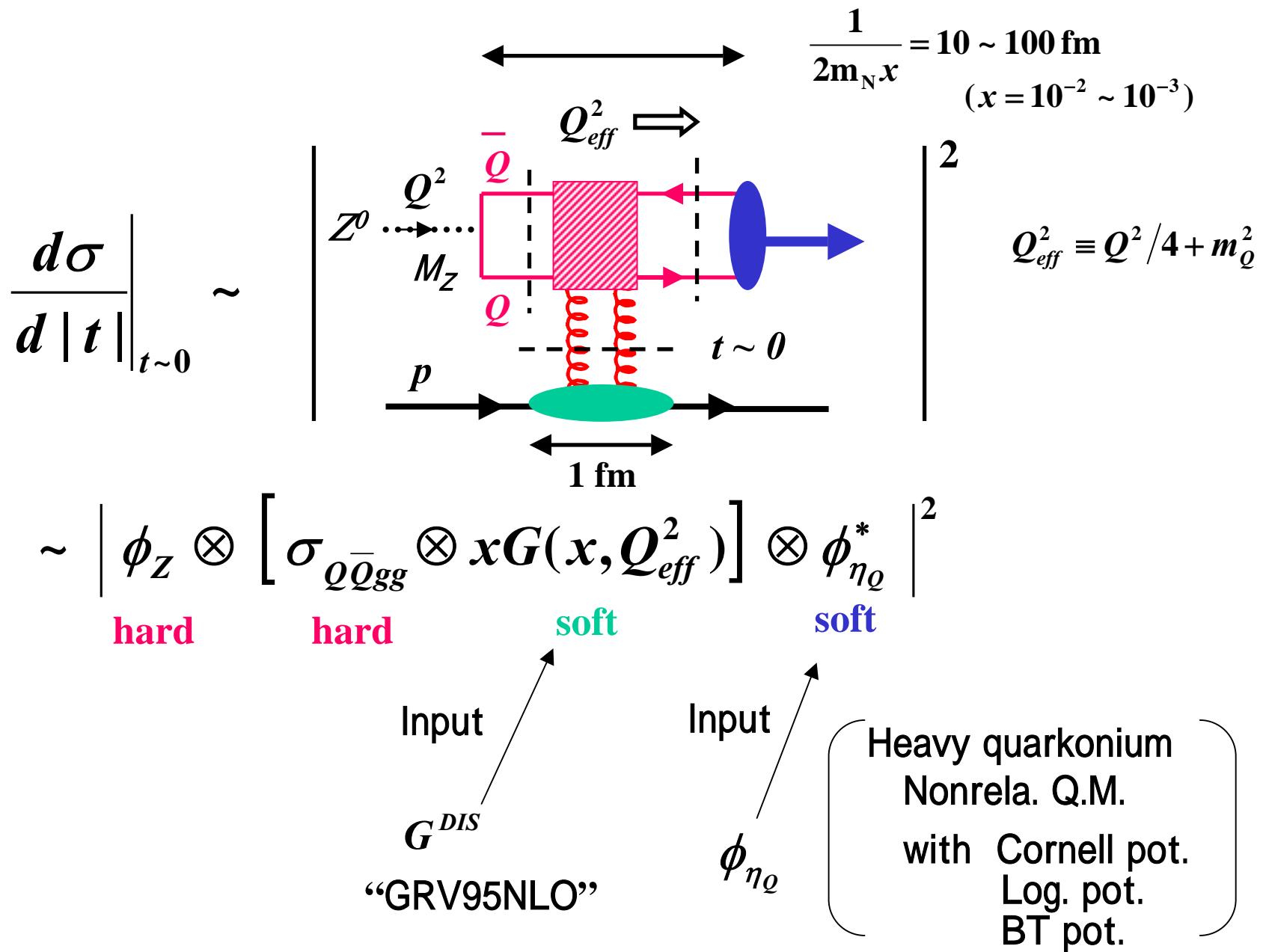


Z⁰ propagator : $\frac{1}{(Q^2 + M_z^2)^2} \approx 10^{-8} \text{ GeV}^{-4}$ @ $Q^2 = 0$, $M_z \approx 91 \text{ GeV}$

** Neutrino beam facilities **

1. CERN-SPS CDHS('82), CDHSW ('85) :
J/ψ production observed (one data point)
2. Fermilab (NuTeV) E815 ('00) : $\sigma(\nu_\mu Fe \rightarrow \nu_\mu J/\psi Fe) \leq 0.21 \text{ fb/A}$
(but no evidence)
3. CERN-SPS CHORUS
4. Fermilab Tevatron E632

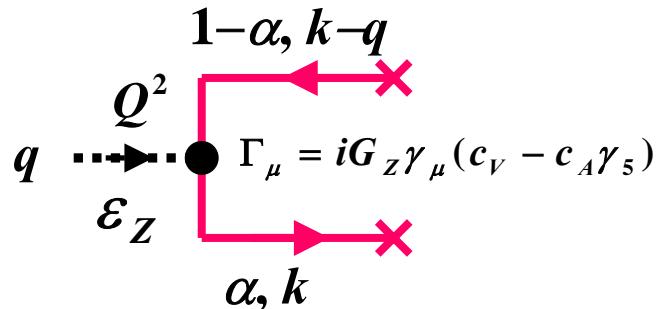
** Color dipole-nucleon dynamics in PQCD **



** Light-cone wave functions **

Light-cone perturbation theory Ref.. Lepage-Brodsky ('80)

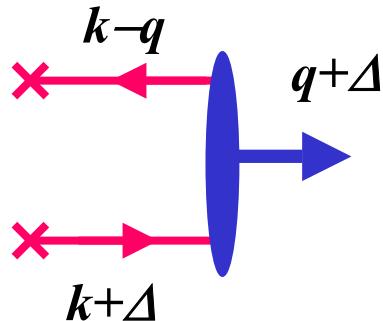
“Z⁰ part”



$$\phi_{LC\lambda'\lambda}^{Z(\text{pol.})}(\alpha, k_T) =$$

$$\frac{\bar{u}_{\lambda'}(k)}{\sqrt{k^+}} \Gamma \cdot \varepsilon_Z \frac{v_{\lambda}(q-k)}{\sqrt{(q-k)^+}} \frac{1}{q^- - (k-q)^- - k^-}$$

“η_c or η_b part”



$$\phi_{LC\lambda'\lambda}^{\eta_Q}(\alpha, k_T) = \underbrace{\frac{\bar{v}_{\lambda}(q-k)}{\sqrt{1-\alpha}} \gamma_5 S}_{\text{Perturbative}} \underbrace{\frac{u_{\lambda'}(k+\Delta)}{\sqrt{\alpha}}}_{\text{Non-perturbative}} \frac{\hat{\phi}_{\eta_Q}^{LC}(\alpha, k_T)}{M_{\eta_Q}}$$

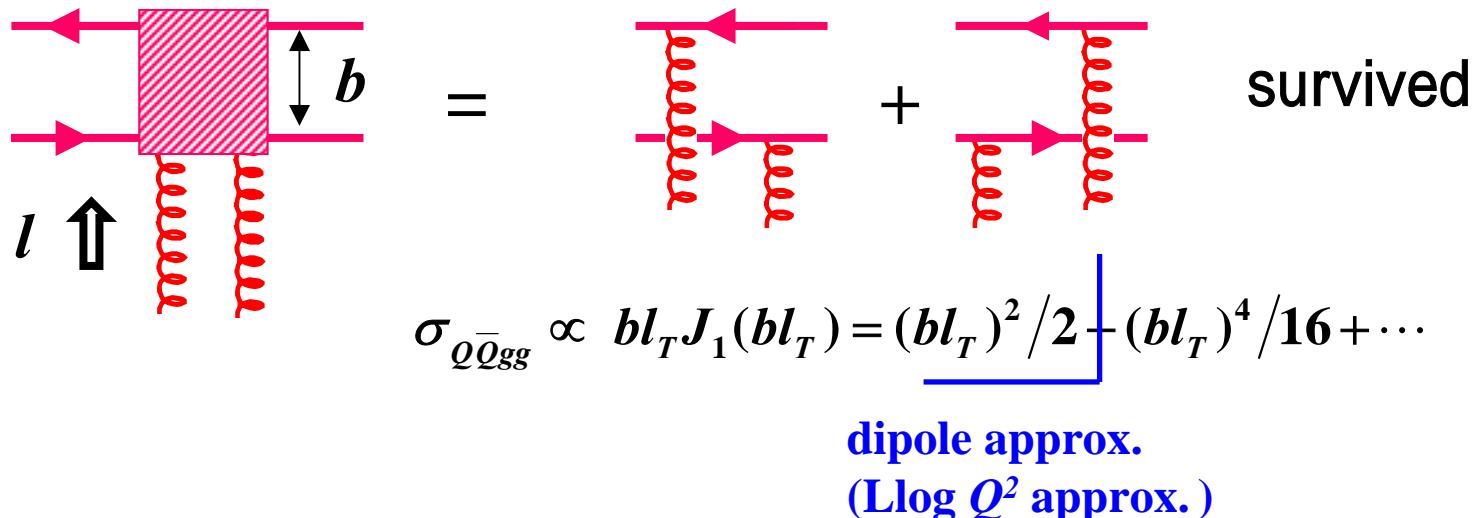
$$S_\mu = \frac{1}{2} \left(1 + \frac{q_\mu + \Delta_\mu}{M_\eta} \right)$$

$$\hat{\phi}_{\eta_Q}^{LC}(\alpha, k_T) = \left(\frac{k_T^2 + m_Q^2}{4\{\alpha(1-\alpha)\}^3} \right)^{1/4} \phi_{\eta_Q}^{NR} \left(|\vec{p}| = \sqrt{\frac{k_T^2 + (2\alpha-1)^2 m_Q^2}{4\alpha(1-\alpha)}} \right)$$

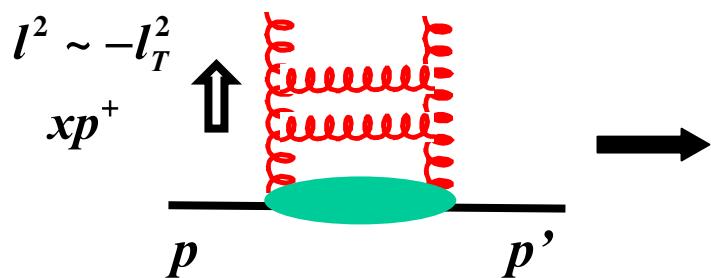
** Description of interaction cross section **

“ $Q\bar{Q}$ -gg interaction”

Ref. Frankfurt, Koepf, Strikman ('96, '98),
Ryskin, Roberts, Martin, Levin ('97)



“Gluon ladder diagram”



BFKL equation

Ref. Kuraev, Lipatov, Fadin ('77)
Balitskii, Lipatov ('78)

“*Unintegrated*” gluon density

$$f(x, l_T^2) = \frac{\partial (x G^{DIS}(x, l_T^2))}{\partial \ln l_T^2}$$

** Analytic results **

$$\text{Amplitude : } A_{\eta_Q}(Z^0 N \rightarrow \eta_Q N) \sim \phi_Z^{pol.} \otimes \left[\sigma_{cc\bar{c}gg} \otimes xG(x, Q_{eff}^2) \right] \otimes \phi_{\eta_Q}^*$$

$$\left\{ \begin{array}{l} A_{long.}^{\eta_Q} = -\frac{\sqrt{2}\pi^2 W^2}{\sqrt{N_c}} \frac{g_W m_Q c_A}{M_{\eta_Q} Q \cos \theta_W} \frac{M_{\eta_Q} + 2m_c}{2M_{\eta_Q}} \alpha_s(Q_{eff}^2) \left[1 + i \frac{\pi}{2} \frac{\partial}{\partial \ln x} \right] xG(x, Q_{eff}^2) \\ \times \int_0^1 \frac{d\alpha}{\alpha(1-\alpha)} \sqrt{\alpha(1-\alpha)Q^2 + m_Q^2} \int_0^\infty db b^2 \hat{\phi}_{\eta_Q}^*(\alpha, b) K_1(b \sqrt{\alpha(1-\alpha)Q^2 + m_Q^2}) \\ A_{trans.}^{\eta_Q} = 0 \end{array} \right.$$

“Total cross section”

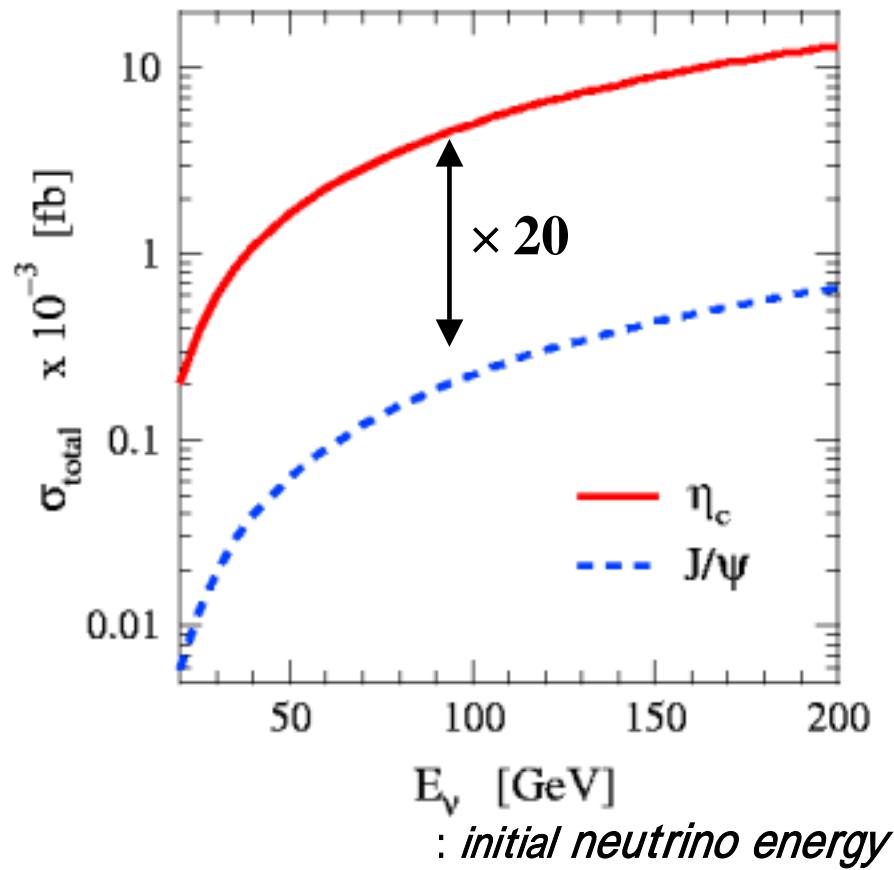
$$\begin{aligned} \sigma_{total}^{\eta_Q}(E_\nu; \nu N \rightarrow \nu' \eta_Q N') &= \frac{g_w^4}{4(8\pi)^3 E_\nu^2 M_N^2 B_{\eta_Q} \cos^2 \theta_W} \int_{M_{\eta_Q} + M_{\eta_Q}^2 / (2M_N)}^{E_\nu} d\nu \\ &\times \int_0^{4E_\nu(E_\nu - \nu)} dQ^2 \frac{1}{\nu} \frac{Q^2}{(Q^2 + M_Z^2)^2} \frac{\varepsilon}{1-\varepsilon} \left| A_{long.}^{\eta_Q}(\nu, Q^2) \right|^2 \end{aligned}$$

Diffractive slope parameter : B_{η_Q} Z^0 polarization : ε

*** Numerical results ***

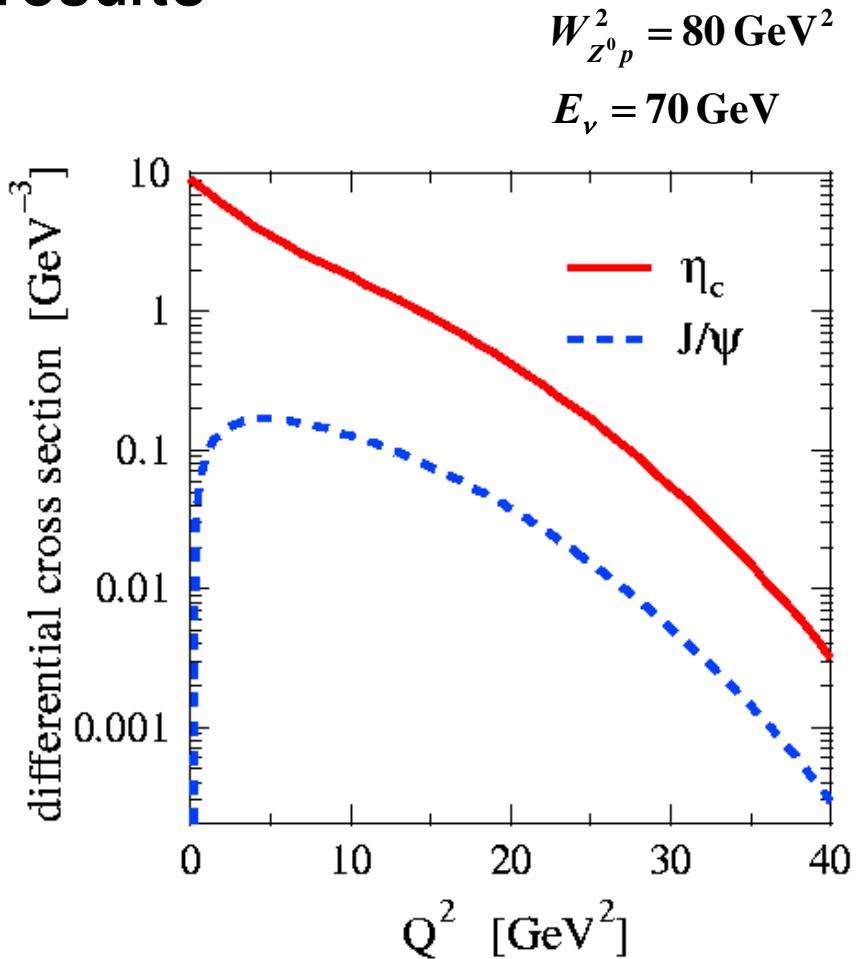
$$B_{\eta_c} = B_{J/\psi} = 4.5 \text{ GeV}^{-2}$$

$$m_c = 1.5 \text{ GeV}$$



: initial neutrino energy

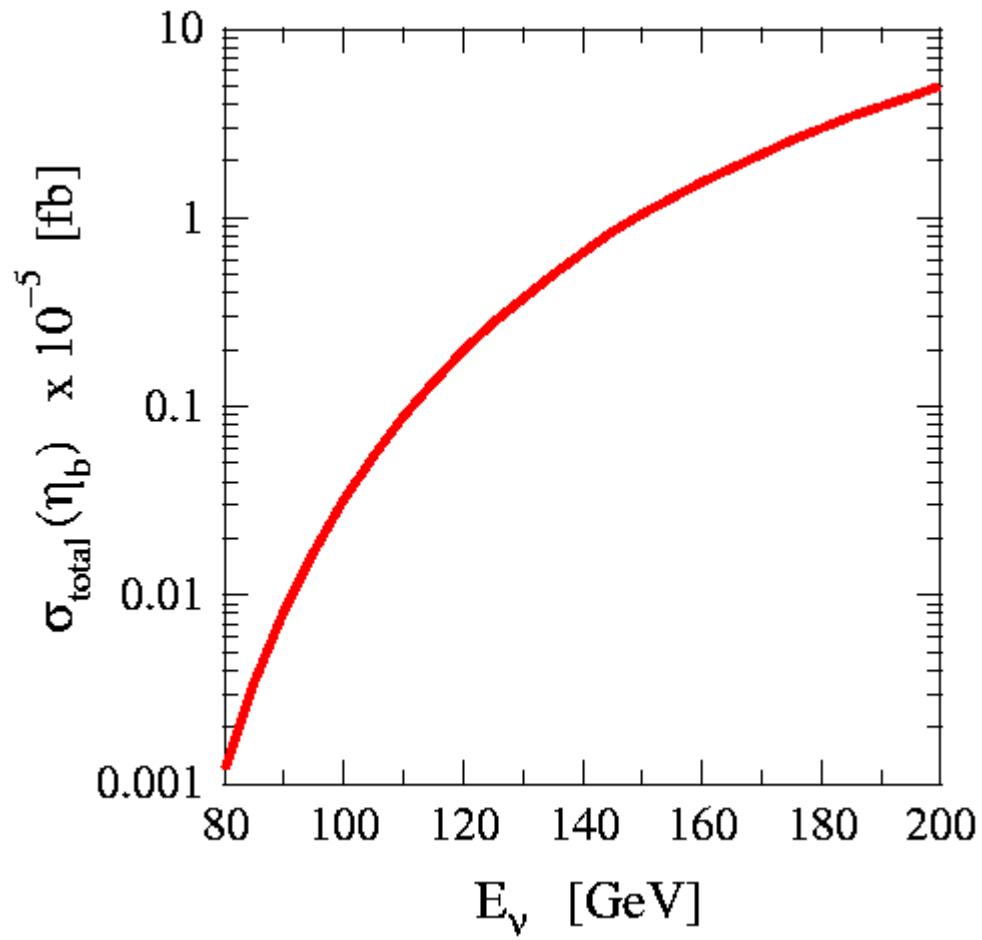
Similar behavior to π -production:
ref. Kopeliovich-Marge, Int.J.Mod.Phys.A8('93)



$$A_{\eta_c} \rightarrow b^2 K_1 \left(b \sqrt{\alpha(1-\alpha)Q^2 + m_c^2} \right)$$

$$A_{J/\psi} \rightarrow b^3 Q K_{0,1} \left(b \sqrt{\alpha(1-\alpha)Q^2 + m_c^2} \right)$$

η_b production



$$B_{\eta_b} = 3.9 \text{ GeV}^{-2}$$

$$m_b = 4.9 \text{ GeV}$$

** Summary **

1. New physical states, η_c and η_b in neutrino-induced diffractive productions are studied through hard Pomeron exchange.
2. PQCD technique used in J/ψ diffractive electroproductions is applied with new construction of light-cone wave functions for Z^0 and $\eta_{c,b}$.
(within dipole approx., with relativistic corrections being retained explicitly)
3. The total cross sections (TCS's) allow only contribution from the longitudinal polarization of Z^0 within these approximations.
4. The TCS of η_c monotonically goes up with increasing $E\nu$. The magnitude is about 20 times as large as that of J/ψ diffractive production by weak neutral currents.
5. At $E_\nu \sim 200$ GeV, the TCS of η_b is about only 10 times as small as that of J/ψ diffractive production by weak neutral currents. This would be accessible process in which we can first observe η_b